James Watt: Father of Steam Power

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This article describes the success story of James Watt who had humble beginnings and yet changed the course of history by paving the way for the Industrial Revolution through his great inventions.

Introduction

The Industrial Revolution, starting in the latter half of the 18th century and still under way, is a momentous turning point in human history. In a little over two centuries it has transformed human society more than all the other developments in the course of the thousands of years of recorded history did. A human being of the 16th century for example, if he could come back, would be utterly bewildered by what he would see in a great city of today in a developed nation – trains, cars, planes, electrical power, etc., – which were undreamt of in his days.

Steam Power

It all started with the advent of steam power a little over two centuries back. The power of steam had been recognized by some like Hero of Alexandria as early as the 1st century of the Christian Era. He made a hollow metal ball rotate on bearings by letting out steam from diametrically opposite directions. But the possibility of its large-scale application was not recognized and the matter rested there for many centuries.

From the 16th century onwards serious efforts to use steam power got under way. Among the almost forgotten early pioneers in this field are Blasco de Garay of Spain and Edward Somerset and Thomas Savery of England. But the first man who succeeded in producing a practical steam engine (in 1712) was Thomas Newcomen (1664–1729), a self-employed iron worker of rural England.

Keywords
James Watt, steam engine, condenser.

In the later part of the 17th century, coal was beginning to be a major fuel in England. But its mining was plagued by a serious problem – flooding of the mine by subsoil water. Men and horses could not remove this water fast enough and coal output suffered seriously. This need for pumping out the water fast was the driving force behind the quest for steam power. Later, the rapidly expanding textile industry and the production of iron offered ready areas for the use of large amounts of steam power.

Newcomen Engine

In the Newcomen engine a boiler raised steam and the steam was admitted into a piston and cylinder mechanism by the opening of a valve. The piston moving up caused a pump rod to move down by a rocker arm mechanism with a fulcrum. The steam inlet valve was then closed and cold water injected into the steam cylinder. This condensed the steam and atmospheric pressure forced the piston down and the pump rod up, causing water to be pumped out.

The overall efficiency of the Newcomen engine, based on heat input to the boiler and the physical work done in pumping out water, was very low, less than 5%. But still, since it used readily available coal in the mines as fuel and did the work of a large number of horses and men in pumping out water, it was widely used for several decades in the coal mines. The situation was ripe for a mechanical genius to step in and improve the steam engine to the point where it would become a widely used source of power.

James Watt

The man who vastly improved the Newcomen steam engine and made it effective enough to propel the Industrial Revolution in its early stages was James Watt (1736–1819). Though he did not invent the steam engine, his improvements on it were so seminal that he could be practically considered the Father of Steam Power.

This first of the great inventors of the modern era was born in Greenock in Scotland on 19th January, 1736. His father, also James Watt, was a master instrument maker and repairer, particularly of nautical instruments. The younger James thus grew up in an atmosphere of mechanical contrivances. His natural bent too was in that direction and hence there was never any question about what trade he would take up as an adult. In addition to skilled hands, he also had a highly enquiring mind, constantly absorbed not only in understanding the working of instruments but also in trying to improve them.

James was a sickly boy and of lonely temperament. So in the early years his education was at home. But they were not wasted years, with the ready availability of his father's workshop. He was also an avid reader and hence was quite well informed about many fields.

James eventually started attending school. He was not particularly distinguished, but his innate ability began to be noticed. In the subsequent years two setbacks affected him. His father's financial position deteriorated and his mother died when he was about 18. James decided to seek his fortune and left for Glasgow, one of the major cities of Scotland. His several years of experience and study in the field of instruments made James believe that he was ready for a short apprenticeship with a master instrument maker, to be followed by starting off by himself. But he found no one in Glasgow who could train him and some friends of his family advised him to go to London, the capital of Britain and one of the premier cities of the world. It was also home to some of the best instrument makers in the world.

Accordingly, James set out for London in June 1755. He went on horseback, with a friend. The less than six hundred kilometers journey from Glasgow to London took twelve days! Though he did not know it then, James Watt himself was to later contribute much to shortening such travel times through the application of steam power to railways and passenger ships.

Apprenticeship in London

Inspite of all his skills and keenness James found the situation very grim in London. Each trade had its own 'Guild', an organization to control the recruitment and training of apprentices. 'Outsiders' were not welcome and even the selected apprentice had to undergo a seven-year long training (too long for Watt) before being allowed to set up his own business. The ostensible purpose was to maintain high standards, but the real aim was to restrict competition! We see much the same type of vested interests operating today also in different parts of the world. Human nature is something beyond the control of science and technology.

Stymied by such restrictions James struggled to find a trainer and at last found one in an instrument maker named John Morgan, who was prepared to let him work with him for a year, provided James paid a fee and asked for no wages! Still James accepted it gladly, given the circumstances. Fortunately, Morgan was capable in his trade and James Watt did learn much from him.

It was a harsh life for James in London. Given his father's difficulties he found it hard to meet his living expenses. Another peculiar threat also bothered him. Britain's Royal Navy, the greatest navy in the world and the pride of the nation, could not find enough young men to man its ships voluntarily. The solution was to send gangs of tough sailors at night into the streets of London to kidnap unwary youngsters and press them into naval service (very aptly they were known as 'Press Gangs'!). In addition to miserable living conditions, James was hence forced to remain confined to his room after sunset.

Return to Scotland

It was with a feeling of relief that James Watt concluded his training and traveled home to Grenock in July 1757. After a short stay with his family he set out for Glasgow to find work. Here again, he found the instrument makers' guild blocking his way, with a demand for seven years' apprenticeship. Fortunately, through some friendly professors in Glasgow University he found it possible to become the instrument maker and repairer for the university inside its campus (not covered by the Guild!).

James quickly gained a reputation in the university. If some instrument stubbornly refused to function, the decision always was "take it to James". His innate enquiring nature and wide reading also brought Watt into contact with two eminent professors, Joseph Black and his pupil John Robinson, who became his good friends. In particular, Black worked on heat. The field then was dominated by the concept of `Caloric', a mysterious invisible substance that was supposed to flow between hot and cold bodies. It required the work of several eminent scientists, among whom Joseph Black is to be included, to discredit this theory. Black also studied the phenomenon of Latent Heat and investigated the specific heat of substances.

Watt and the Steam Engine

In October 1759 Watt left the University to start his own business in Glasgow city, but maintained his contacts with both the university and his personal friends. His reputation as an instrument repairer was now solid. Even musicians brought their instruments to the utterly unmusical Watt and he not only repaired them but also incorporated several improvements in them!

In the academic year 1763–64, Professor John Anderson of Glasgow University asked Watt to look into a model of the Newcomen engine which was failing inspite of repeated efforts. James accepted it. Neither he nor Anderson realized what they were starting.

Watt could not make the model function for more than a few strokes. Greater heating of the boiler failed to solve the problem. With his interest in heat kindled by Black and Robinson, Watt determined to get to the root of the problem. It was clear to him that much of the energy of the steam was wasted by condensing it with a spray of cold water. Not only the steam but the cylinder also lost heat and had to be reheated in the next cycle. But what was to be done to rectify it? The answer was not so easy to come by. The problem bugged him greatly and distracted him from his other work for quite some time.

The Solution

The solution, as for so many great inventors, came in a flash when he was not actively working.

He was having a relaxed walk in a park on a Sunday evening in April 1765, when the solution flashed to him: the measures he envisaged were:

- The steam cylinder should be kept as hot as possible by jacketing it with steam straight from the boiler.
- The condensation of the expanded steam should take place in a separate vessel (he gave it the still-used name "Condenser"), which would be evacuated by a pump, drawing out both condensed steam and any air. Thus a partial vacuum will be achieved, helping to draw out the steam from the cylinder, when a valve opens a passage to the condenser at the end of the expansion stroke.
- The piston movement would be achieved by the action of steam and not atmospheric pressure as in the Newcomen engine.
- The cylinder head will be closed and have a steam-tight stuffing box to pass the piston rod.

Impatiently Watt waited for the next day and lost no time in constructing a model. It was a make-shift affair, built with readily available parts. It was not too successful but Watt saw its potential. The historic engine is now a valuable exhibit in the National Science Museum at South Kensington in London. He started the construction of a better model with some financial help from Dr John Roebuck, an industrialist friend of Prof Black. He faced serious problems. The chief one was that cylinders could not be bored accurately and consequently steam leakage was heavy.

Commercial Application

Years of struggle and disappointment followed. Dr Roebuck was declining financially and his help to Watt was on the wane. In 1766, Watt was forced to take up additional work as a Civil Engineering Surveyor, a profession for which he was ill-suited. But now fate intervened. During one of his trips to London, James met Matthew Boulton, the son of a Birmingham engineer. Boulton took an instant liking to Watt and appreciated his ideas. Enthused, Watt filed a patent for his engine in 1769.

Mathew Boulton was the exact opposite of James Watt in temperament. He was an extrovert, a good organizer and an excellent financial manager. Once they started working together, Boulton ably managed the business part and left Watt to concentrate on what he did best – inventing. Their friendship was to last all their lives. Some historians of science and technology even feel that without Boulton, Watt could not have achieved the transition from invention to commercial application and success. As with many other inventors, seasoned industrialists might have profited from the inventor's work, leaving him out in the cold.

Watt's earlier benefactor Roebuck went bankrupt. His creditors took no notice of the crude steam engine. In their eyes it was junk. Boulton gladly took it over and brought Watt to Birmingham to work with him. Boulton, with his wide contacts, located one expert machinist, John Wilkinson, who had developed a method to bore out cylinders accurately. His cylinders worked perfectly. Boulton also pressed Watt to renew his patent for another 25 years. This was done in May 1775. Boulton's intervention was also required to help the shy and nervous Watt to persuade parliamentary representatives in London for the patent renewal.

The first two commercial steam engines began operation in March 1776. They were four times as efficient as the Newcomen engine. A brief report appeared in newspapers, but possibly not even Watt and Boulton realized that they were setting in motion the Industrial Revolution. In the subsequent years while the business part flourised under the management of Boulton, Watt came out with a series of new inventions. He used a sun-and-planetary mechanism to convert the reciprocating piston movement into a rotary one (later repaced by connecting rod – crank mechanism). Now the steam engine could drive any machinery, and not just pumps. Since steam engines could be set up anywhere (unlike water-wheels), the factory system came into existence, replacing cottage industry. Production of goods, particularly textiles increased several orders of magnitude. Watt also developed the double-acting steam engine, the throttle valve for controlling steam flow to the cylinder, the centrifugal governor for regulating the engine speed and indicators for measuring the steam pressure in the cylinder. He even developed a copying process for documents!

The one respect in which James Watt failed to anticipate future developments in steam engines was with regard to the use of high pressure steam. He felt it was too dangerous. But other engineers found ways to use high pressure steam with safety. Compound expansion, that is, expanding the steam in a high pressure cylinder and then in lower pressure cylinders followed.

Double-acting Steam Engine

Figure 1 represents a double-acting steam engine in the basic form. Steam from the boiler is admitted to a chamber which communicates with both ends of the cylinder. A 'D-slide valve' driven by an eccentric disc on the cranksfaft alternately opens the two passages. When fresh steam is admitted to one side of the cylinder, exhaust steam is being pushed out from the other side. Thus the output is practically doubled. A crosshead and crank mechanism converts the reciprocating motion of the piston into rotary motion.

Figure 2 shows a typical indicator diagram for the Watt Steam Engine. The inlet passage opens at 1 and steam entry is cut off at 2. Expansion continues and the exhaust passage is opened at 3. Exhaust steam is pushed out until the passage closes at 4. The losses associated with a steam

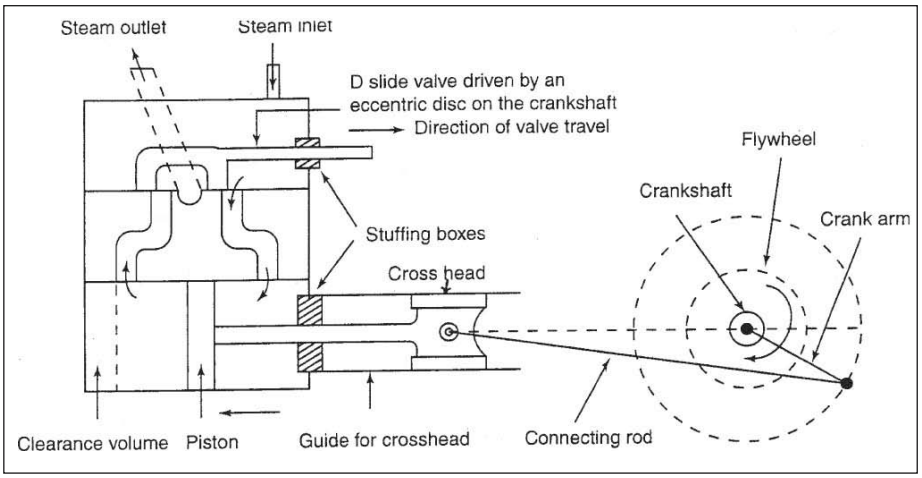


Figure 1. The Double-acting Steam Engine

engine are heat losses through cylinder walls, etc., clearance volume losses, wire drawing losses (loss of steam pressure in cylinder due to gradual opening of the inlet passage) and throttling losses and friction in engine parts. The inherent limit on the efficiency imposed by the Second Law of Thermodynamics was realized only many years later. It had to await the development of the science of thermodynamics.

Later Developments

The steam engine was quickly harnessed for moving goods and people and the Age of Railways dawned with its profound impacts on economy, war, social organization, etc. In the 1880s Gustav Laval of Sweden and Charles Parsons of England developed the steam turbine, a more compact and balanced mechanism for producing power from steam.

Technology is a fast-advancing field and the technical wonders of today are made obsolete by the next stage of development. So it has been with Watt's steam engines. They are rarely used today. But each stage of development in technology paves the way for the next stage. Watt's steam engines gave a mighty initial push to the Industrial Revolution and made possible the subsequent continuous progress.

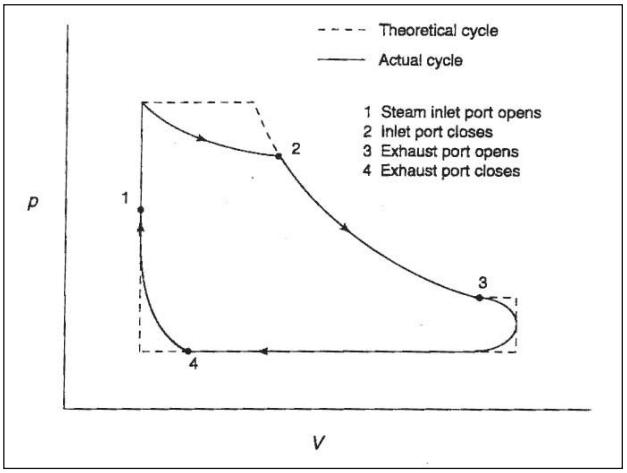


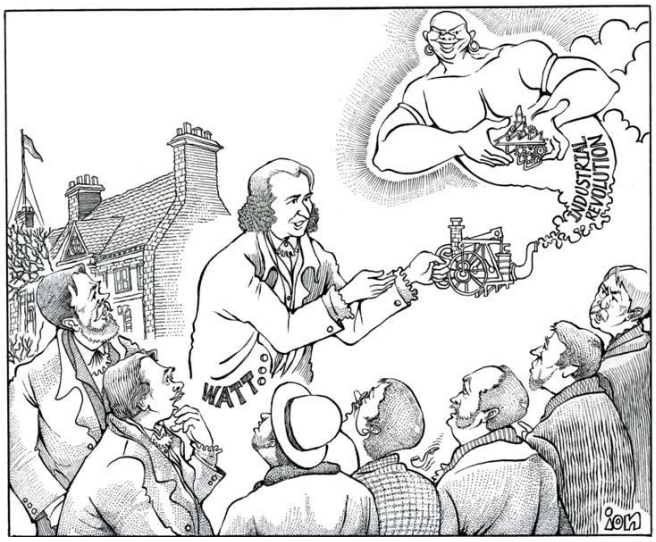
Figure 2. Typical Steam Engine Indicator Diagram.

Personality of James Watt

James Watt was all that popular imagination supposes inventors to be. He was a very original thinker, shy and high-strung. He was totally absorbed in his ideas and oblivious to the realities of the business world. He was also a perfectionist, forever trying to improve on what he had achieved. But fortunately James Watt was very lucky in finding people who understood him and allowed him to work in his own way, while they took care of the aspects in which he was no good. Chief among them was Matthew Boulton. He made sure that Watt's patents were renewed in time. He also released the steam engine for commercial use at the proper stage. Watt wanted to tinker on and on. Above all, Boulton saw to it that Watt derived the financial benefits flowing from his invention.

James Watt was married twice, first to a cousin, Margaret Miller in 1764 and after her death to Ann McGregor in 1776. Both the wives provided him with a stable and quiet home, so necessary for his work. His last years were spent in peace and prosperity. He continued his tinkering in his own workshop even after his retirement in 1800, without having to worry any longer about the financial success of his efforts! He died peacefully on 17th August 1819 and was buried beside his friend Matthew Boulton, who had passed away some years earlier.

Honours poured on James Watt and his role in changing the course of history is vividly remembered by posterity. His main work was done at a time when metallurgy, manufacturing and thermodynamics were not established as sciences. With all these limitations, to have developed the steam engine as a practical power plant was an achievement of genius, insight and perseverance.



Crank up some steam in this lamp .. and watch the genie appear